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Trends in Model-Based Definition based Assembly Information for High-Value Manufacturing

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Abstract

3D modeling is in use for the last many decades at various stages of the product lifecycle i.e., design, analysis, manufacturing, and inspection. In the modern era of Industry 4.0 where the high-value manufacturing industry is aiming at the digital thread, Model-Based Definition (MBD) has been considered as the heart of this transformation. However, MBD needs to be realized throughout the product lifecycle to get full advantage. In literature, considerable work has been found focusing on a shift from traditional 2D drawings to MBD. The majority of this work concentrates on design, manufacturing, and inspection stages, whereas, there is a lack of work in the area of MBD based assembly information. This paper focuses on the current state of knowledge in MBD based assembly information, trends, challenges, and future research directions.

1 Introduction

Manufacturing of high-value products such as aero engines is becoming more complex with the evolution in technology to meet high-performance demands. New methods and means are always required for accurate and efficient manufacturability. Model-Based Definition (MBD) is a 3D digital product model that defines the requirements and specifications of the product. A Model-Based Enterprise (MBE) uses MBD to define the product requirements and specifications, instead of the paper-based document, as the data source for all engineering activities throughout the product lifecycle. In MBE, models drive all aspects of the product lifecycle. This model data is created only once and then reused for all downstream activities (Hedberg *et al.*, 2016). Though MBD is being adopted rapidly, its full implementation throughout the product lifecycle is not fully achieved yet and traditional drawings

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are still in use (Quintana *et al.*, 2010). Researchers have studied MBD implementation at design, discrete part manufacturing, and quality inspection stages; however, assembly, maintenance, sustainment and decommissioning are less addressed areas. The aim of this paper is to have an overview of the literature in MBD-based assembly information and to figure out the current state of implementation and the emerging challenges.

In the next section current trends in MBD-based assembly are overviewed, followed by the conclusions and the literature gaps.

2 Current Trends

Assembly is a crucial stage in the product lifecycle, which involves combining and connecting individual parts at their designed positions. It is accomplished with the help of design drawings and technical requirements. Assembly in high-value manufacturing involves large number of parts and tooling. The assembly operations are manual with partial to no-automation. Sometimes, restricted space is also a constraint. Assembly information documents are used at the assembly shop floor to help the workers carry out these operations. These documents are based on the original design and mostly, this information is drawing oriented. This form of assembly information instructs complex levels of text meaning a vast amount of documents are issued to the shop floor. To consult these documents a lot of time is needed along with the skill of assembly workers. These difficulties affect quality and productivity. Adding to severity, a change in original design requires change in all that pile of information, which again costs time and money. Assembly teams are not getting yet the potential benefit from 3D modeling, although 3D modeling is gaining fast adoption. Assembly information based on 3D modeling is evolving in combination with other technologies like Digital Mock-up, Virtual Reality and Augmented Reality. These technologies need the use of expensive equipment at the shop floor, the use of which is sometimes not feasible. Their applications are at experimental or prototype stages and they lack all the details available in drawing based assembly information. Moreover, the solutions are offline, which again affect the value chain if the design changes are frequent.

We have figured out the recent trends of work in the field of MBD-based assembly information. **Figure 1** gives an overview of the key areas addressed in the literature.

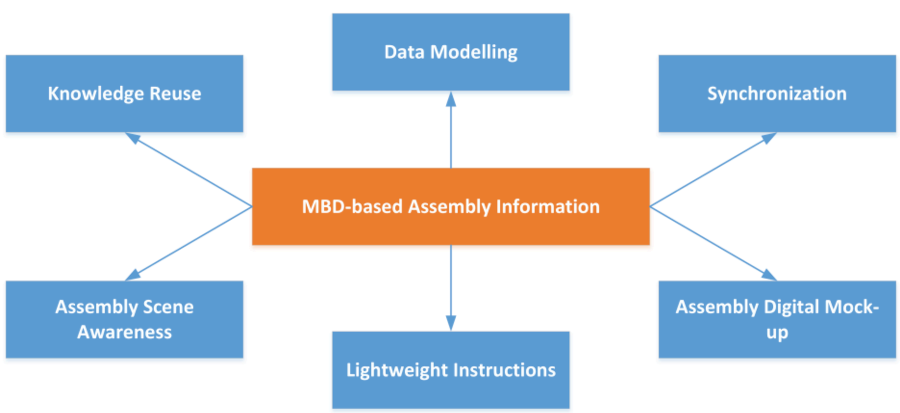

Figure 1: Key Areas Addressed

In an effort to make knowledge reuse and reduced dependence on the designer's knowledge, Zhang et al. (2019) presented the smart jig model for agile joint jig (AJJ) by integrating jig design knowledge i.e., configuration rules and information in to the 3D model using MBD. They established information model with MBD that included product general information and assembly process information to enable automated designing of the jig. Auto-selection reasoning was combined with auto-assembly reasoning for this purpose. According to the authors, the previous practice of design AJJ was largely dependent upon the knowledge of the designer and required excessive manual or interactive decision-making.

Xiao et al. (2018) found that the augmented reality-based Assembly Process Instructions (API) largely concentrate on the search and integration of geometric elements in the assembly scene. The existing practices ignore assembly tools and semantic elements. Moreover, full information of the assembly scene is not considered. The current APIs are offline demonstrations, which disconnect virtual information with the real assembly situation. By designing an assembly feature recognition algorithm based on MapReduce, they investigated a dynamic assembly simplification method with assembly feature preservation to support downstream 3D API construction and transfer. In addition, an AR-based method for API construction and transfer to assembly location was proposed by adding assembly scene information.

Geng et al. (2015) proposed a method to get the advantage of 3D annotations at the assembly shop floor by eliminating the need of heavy system and software requirements. They presented a solution, which used a normal computer, hence decreasing deployment cost. The method took benefit from the accuracy, clarity, and unambiguity of the 3D model to take into account the intent and requirements of assembly. The benefits obtained in the transformation from 2D information to 3D information were also measured and highlighted. In another effort, Geng et al. (2014) worked on maintenance, repair and overhaul (MRO) planning for accuracy of the content description and on-site guidance for complex products by proposing a design method for MRO job cards based upon MBD. The method was applied on an aircraft right wing assembly and the benefits obtained from this shift from 2D to 3D job cards were reported. Sequence planning was used to design assembly and disassembly order of the parts while path planning was used to design the movements of parts in the assembly/disassembly processes. Use of annotations was also done on the 3D model for technical requirements. This assembly /disassembly process was simulated for collision detection between parts/tools. They took 3D views of all the sequences in the simulations and then combined, integrated and published in 3D lightweight MRO job cards. This job card was designed so, in order to be distributed on mobile workstations or touch screen computers for helping the workers. It was managed to simulate MRO animations, view the geometry and interact with the job card for other detailed information.

A concept of Assembly Digital Mock up (ADMU) was introduced by using an approach of transmission of the model and attribute data to Engineering Bills of Material (EBOM) automatically (He *et al.*, 2014). After receiving design data, they revised the BOM from EBOM to Process Bills of material (PBOM). It followed the reconstruction of BOM of design DMU to gain BOM of ADMU, which is the data source for the assembly process design. ADMU incorporates some information, which is not there in DMU, like, fasteners, craft equipment, tools, and accessories. They structured the product attribute in the ADMU by including both static and dynamic attributes. This ADMU was released for onwards assembly process planning.

McCarthy et al. (2008) in a project of AH-64 composite tail boom manufacturing used MBD for the provision of geometric data for assembly simulation and for assembled FEA. In another work a technology road map for the 3D production process was presented (Meng and Yan, 2013). The information definition for the 3D process model was outlined and it was described that how the system builds on that information. An effort was done to integrate 3D process design and simulation systems by completing the inter-relationship of instructions, information, and data generated in the design and simulation stages. The result from the previous stage was integrated to the Manufacturing Execution System (MES) and was delivered to the production site for visual assembly. The proposed data after release comprised of the data model aiding digital inspection, the lightweight 3D model for visualization manufacturing environment along with some text-based information and the data table. Wang et al. (2013) proposed an MBD data set for drafting. They outlined and categorized the 2D and 3D assembly models and worked on the automatic generation of BOM from the assembly model.

In this section, research articles and conference papers covering MBD and assembly were explored. The following lines describes the gaps and future work directions in this area.

3 Conclusions and Future Research

The adoption of Model-Based Definition at the design stage is mature enough. Rapid evolution of semantic technologies for product and manufacturing information (PMI) generation and consumption is enabling speedy adoption of MBD at manufacturing and inspection stages. However, the application of MBD at the assembly stage is limited and still many areas are to be addressed to get the full benefit of MBD in order to pursue the MBE strategy.

Currently, there is a limited use of 3D assembly information in high value manufacturing, with a quite narrow scope of application. Moreover, this information is not synchronized with the original design. Therefore, a change in original design needs to be accommodated in assembly information with a repetition of all activates which consume a lot of time and resources. This leads to the need for synchronization of the original design with the assembly information.

Assembly operations are complex in nature. For handling these complexities, more research work needs to be done, like piping and cabling at restricted assembly spaces. There is a dire need to identify the assembly information that is required to define the model. Frameworks are required for communication of assembly information to the designer. These will enable addressing the assembly needs at the early stages of the design. Additionally, there is a need to define the most suitable layout and configuration of assembly information to fit various situations.

Replacing the drawing based information, having loads of documents, is not a simple task. It needs new ways of data modelling. It also needs some alternative iconic notations for simplification of the assembly information. It has the potential to reduce lead time of products and also improve the quality of the data flow and ultimately the quality of the product to the customer.

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